MODELLING OF THE EFFECT OF THE GAS PROPERTIES UPON THE EFFICIANCY OF THE ARTIFICIAL LUNG VENTILATION

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Abstract

The study deals with theoretical possibility of benefit of heliox usage in the respiratory care. Heliox is a mixture of helium and oxygen, which has a different physical parameters contrary to air. Different physical parameters, mainly the density of the mixture, enable optimize the respiratory care for example by the decrease of the work of breathing. In this study, the effect of the use of heliox as a respiratory mixture upon the total lung impedance is observed using a mathematical model of the respiratory system.

1 Introduction

There is a lot of problems that can lead to the respiratory failure. The respiratory failure requires the connection of the patient on the artificial lung ventilation or the use of another supportive ventilatory technique that enables to ensure the sufficient amount of oxygen for the patient. Despite the use of new ventilatory techniques in the respiratory care, there still remain a lot of patients that have no or small benefit from the use of artificial lung ventilation. One of the new trends in the respiratory care is the minimization of the work of breathing and optimization of the process of spontaneous or artificial lung ventilation. The aim of the introduction of the use of novel ventilatory regimens is minimization of the lung damage. One of the methods that can lead to the reduction of work of breathing is the use of heliox. It can optimize the spontaneous breathing of the patients that suffers for example by asthma [1].

2 Methods

The aim of this study is to simulate the effect of the use of heliox as a ventilatory mixture using a model of the respiratory system implemented in MATLAB. Heliox is a gas mixture of oxygen and helium. If it is used in the respiratory care it is mixed in many cases in 80:20 (70:30) ratio. It means that there is 80 (70) % of helium and 20 (30) % of oxygen in the mixture. Helium is an inert gas. It does not react with the human tissue; therefore the helium has no adverse effects upon the patient even whet it is used for long periods. The main advantage of the helium is lower density contrary to air. Helium has also low molecular weight and high rate of diffusion. It suggests that use of helium in the respiratory care can reduce the work of breathing and improve aerosol delivery in the respiratory system [2]. Gas properties are shown in Table 1.

TAB. 1: GAS PROPERTIES.

Gas	Density ($kg.m^{-3}$)	Viscosity (μ Poise)
O_2	1,429	211,4
He	0,179	201,8
80 % N_2, 20 % O_2	1,293	188,5
80 % He, 20 % O_2	0,429	203,6
70 % He, 30 % O_2	0,554	204,7

Table 1 shows that heliox is a mixture of helium and oxygen with a known ratio. Heliox has a substantially smaller density contrary to air. Density and viscosity of the fluid mainly determines the characteristics of the flow. The laminar flow is viscosity-dependent and density-independent. The flow during laminar flow is described by Hagen-Poiseuille equation:

$$\dot{V} = \frac{\pi.r^4.\Delta P}{8.\eta.l}, \tag{1}$$

where *r* is a diameter of the tube, *ΔP* is the pressure gradient, *η* is the viscosity of the fluid and *l* is the length of the tube.

When the turbulent flow occurs the flow id described by equation:

$$\dot{V}^2 = \frac{4\pi.r^5\Delta P}{\rho.l}, \tag{2}$$

where *ρ* is a density of fluid.

It is evident that flow is smaller during the turbulent flow. The character of the flow is determined by the Reynolds number and it is computed according to the following equation:

$$\mathrm{Re} = \frac{\rho.v.r}{\eta}, \tag{3}$$

where *v* is velocity.

The flow is laminar when the Reynolds number is smaller than approximately 2000. The flow during turbulent flow is less efficient, therefore the effort of the staff is to maintain the laminar flow in the respiratory care. The Reynolds number is much smaller with helium contrary to air or oxygen. In the cases where the air flow becomes turbulent the heliox flow still remains laminar.

The gas flow during an orifice is also described by equation (4):

$$\dot{V} = \left(\frac{2.\Delta P}{\rho}\right)^{0.5}. \tag{4}$$

The flow through an orifice is density-dependent. It means that heliox has theoretical assumptions to flow better through the orifice when compared with air flow or oxygen flow.

The flow through potentially obstructed airway is described by the Bernoulli equation:

$$P_1 - P_2 = \frac{1}{2}\rho.(v_2^{\,2} - v_1^{\,2}). \tag{5}$$

The smaller pressure gradient is required for the fluids with smaller density to maintain the constant flow through the obstructed airway.

The heliox has a smaller density contrary to air or oxygen and presented equations show that heliox should have better flow properties.

Heliox is used in the respiratory care in many cases as a mixture 30 % of oxygen and 70 % of helium (heliox 70:30) and 20 % of oxygen and 80 % of helium (heliox 80:20). The use of heliox is studied in the mathematical model of the respiratory system that was developed to study them mechanical parameters of the respiratory system [2]. The aim of the study is to support the theory that heliox can decrease the work of breathing and optimize the spontaneous breathing of the patient during respiratory disease.

3 Results

The total lung impedance of the respiratory system is studied. The simulations that were conducted on the model are described. The use of heliox mixture 70:30 and 30:70 are simulated in the model.

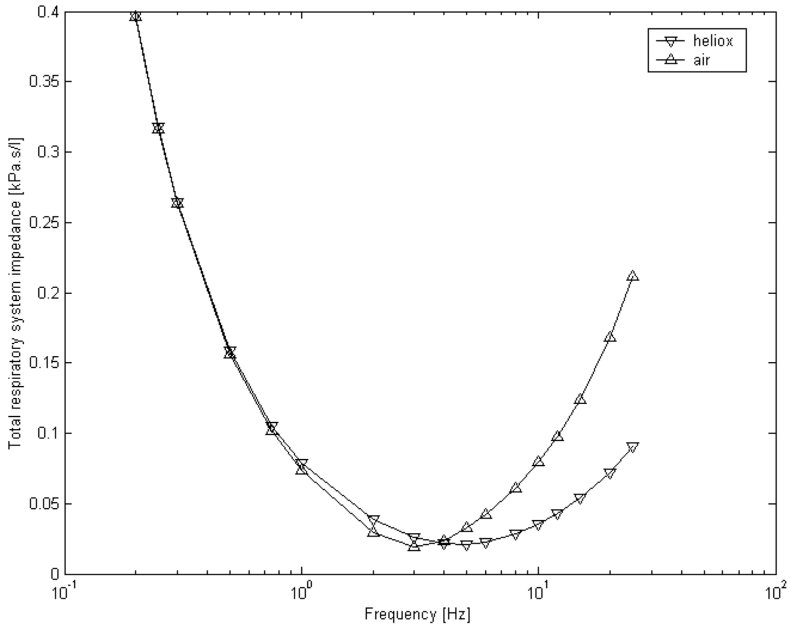

Figure 1: The dependence of the total impedance of the respiratory system upon the ventilatory mixture is depicted for air and heliox 70:30.

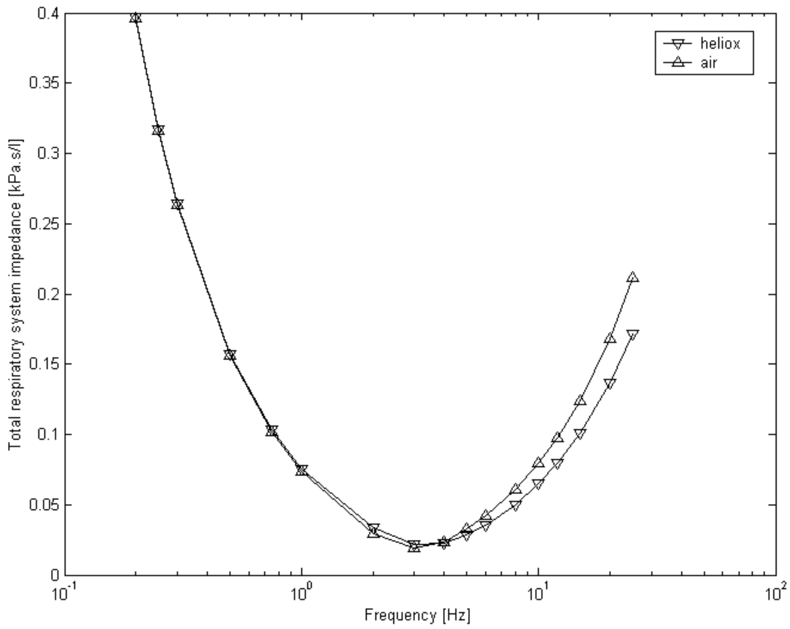

Figure 2: The dependence of the total impedance of the respiratory system upon the ventilatory mixture is depicted for air and heliox 30:70.

The total lung impedance for the heliox 70:30 and heliox 30:70 is shown in Figures 2 and 3. The presented results suggest that total lung impedance is dependent upon the amount of helium in the mixture. The main factor that determines the total lung impedance is the helium density. Helium decreases total lung impedance and it can reduce the work of breathing in cases such as asthma. It is possible to maintain the flow in the obstructed airways with the same pressure gradient.

References

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